End of Life Disposal for Three Libration Point Missions Through Manipulation of the Jacobi Constant and Zero Velocity Curves

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Agenda

- *Introduction/Mission Overview (ACE, SOHO, WIND)*
- *End of Life Disposal Requirements*
- *Circular Restricted Three Body Problem Analysis*
- *Full Ephemeris Analysis*
- *Operational Challenges*
- *Conclusion*

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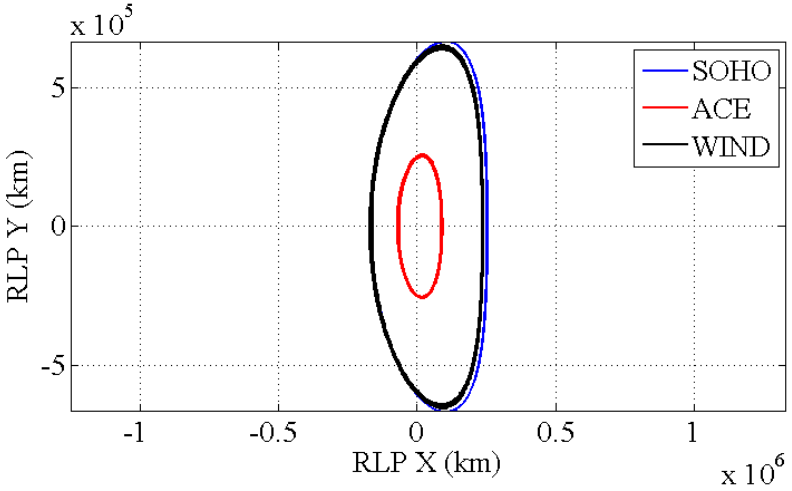
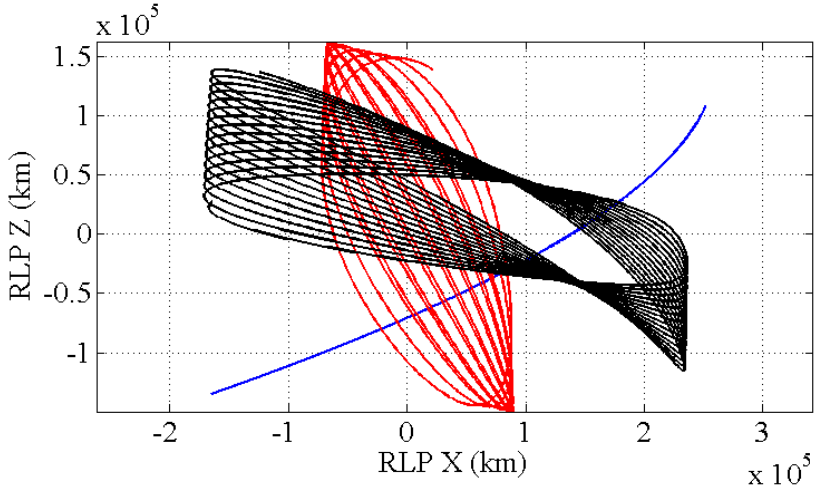
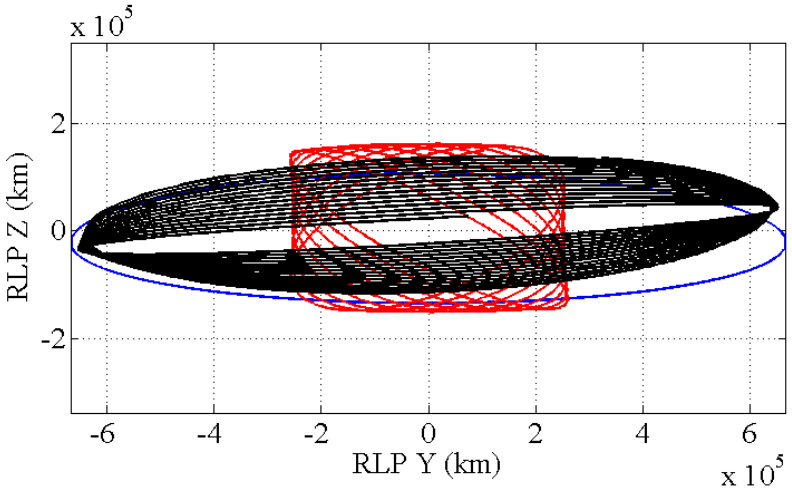
Introduction

- ***Flight Dynamics Facility (FDF) located at NASA Goddard Space Flight Center (GSFC) provides the flight dynamics expertise for three Sun-Earth/Moon L1 missions.***
  - Advanced Composition Explorer (ACE)
    - Launched August 1997
  - Solar and Heliospheric Observatory (SOHO)
    - Launched December 1995
  - Global Geospace Science WIND satellite
    - Launched November 1994
    - Entered Lagrange point orbit in 2004

Mission Overview







- ***SOHO – Large Amplitude Halo***
  - X/Y/Z Amplitude ≈ 206,000/667,000/120,000 km
- ***WIND – Large Amplitude Lissajous***
  - Similar size to SOHO
- ***ACE – Small Amplitude Lissajous***
  - X/Y/Z Amplitude ≈ 80,000/260,000,158,000 km

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End of Life Requirements

- ***NASA has established requirements for end of mission planning which include standards for limited debris in the orbit regimes that are most densely-populated with active missions. [NPR 8715.6A]***
  - Spacecraft must be removed from these protected regions within 25 years after the mission is completed; or,
  - If the mission lasts longer than five years, the spacecraft must be remove 30 years after launch.
- ***For LEO missions, the requirement is most frequently accomplished by lowering the orbit, either actively with thrusters or passively due to atmospheric drag, and re-entering the atmosphere.***
- ***For medium or geosynchronous Earth orbits, several altitude bands have been defined for graveyard orbits.***
- ***Interplanetary missions, including heliocentric trajectories, have a distinct set of requirements with the primary goal of preventing inadvertent biological contamination. [NPR 8020.12 D]***
- ***Deep space missions that do not target celestial objects (such a libration point orbiters) do not have these restrictions imposed on them unless an Earth return is planned.***
- ***Given the age of these missions, it is prudent that a proper post-mission disposal strategy has been developed.***

Previous Libration Missions

- ***11 missions sent to Sun-Earth/Moon L1/L2***
  - Five active
    - ACE/WIND/SOHO/DSCOVR – Active at L1
    - GAIA – Active at L2
  - Six decommissioned
    - ISEE-3 – Sent to make first-ever flyby of a comet
    - Genesis – Solar wind sample return mission
    - Chang'e 2 – Visited an asteroid
    - WMAP, Herschel, and Planck – Placed into heliocentric orbits outside Earth's orbit
- ***The focus for this investigation is heliocentric orbit disposal through closing the L1 gateway with a large ΔV.***
  - Done to reduce complexity and risks

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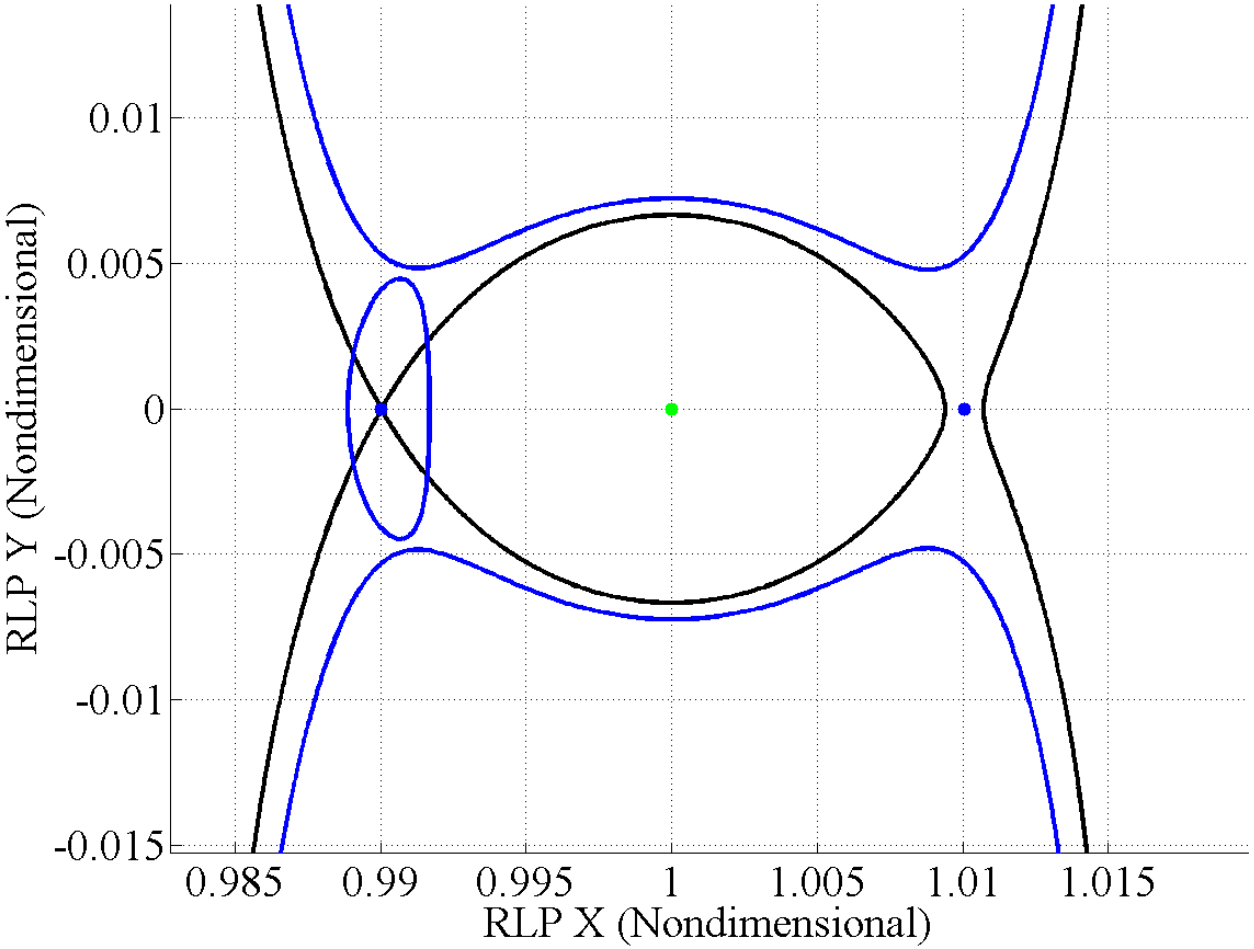
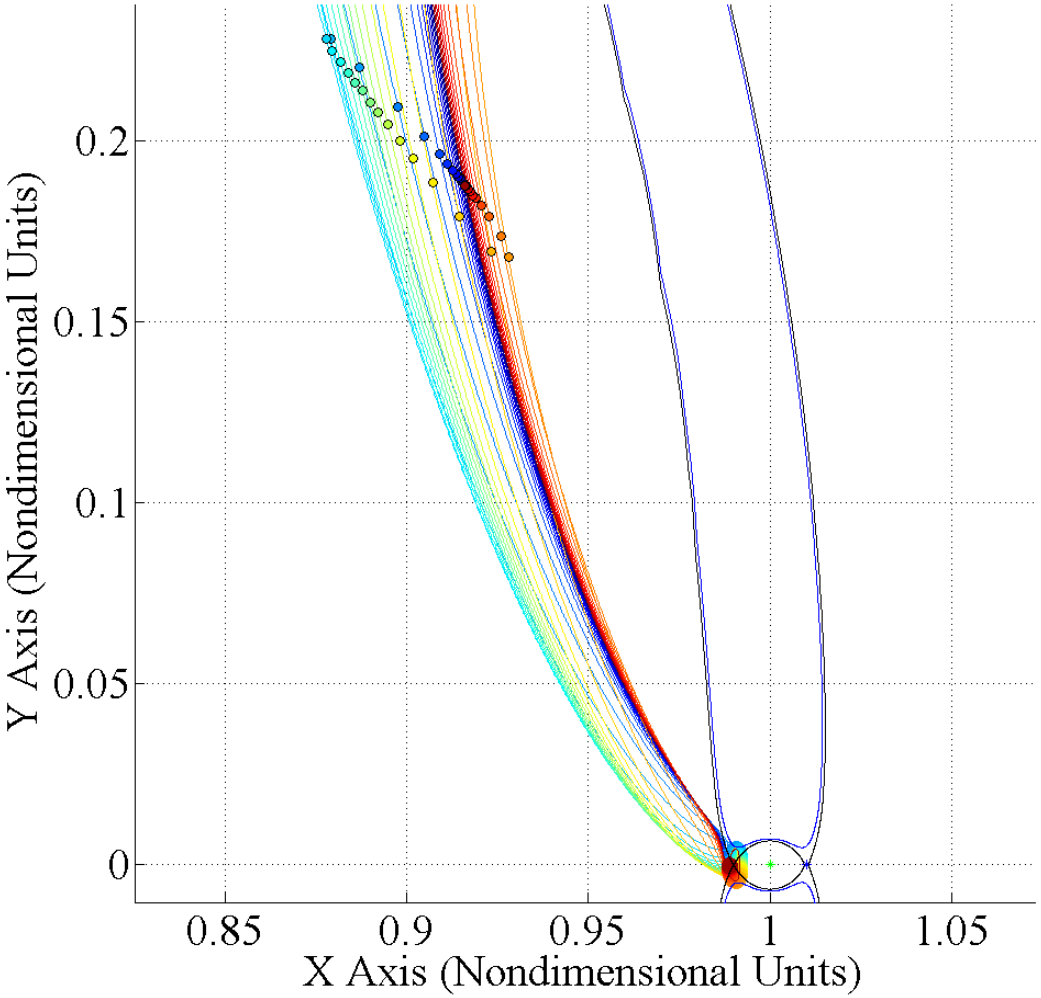
Circular Restricted Three Body Problem

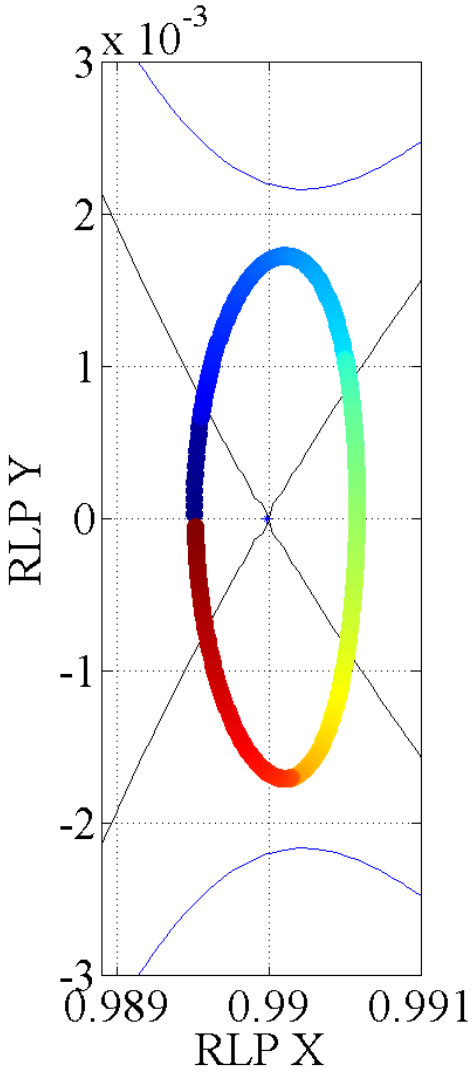
Operational Orbit and Associated Zero Velocity Curves

Closed L1 Gateway Zero Velocity Curves

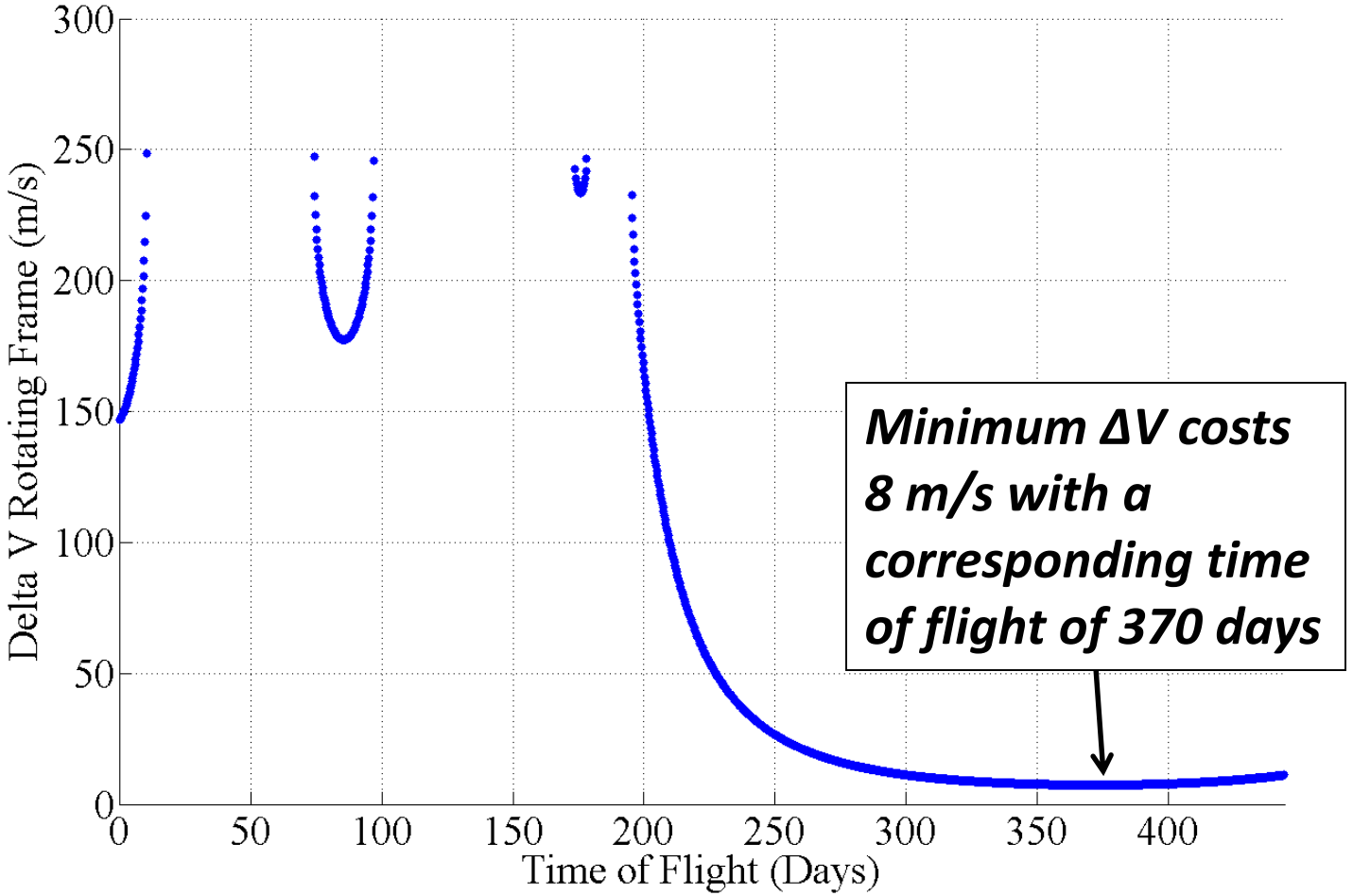


Departure Arcs / Departure Phase

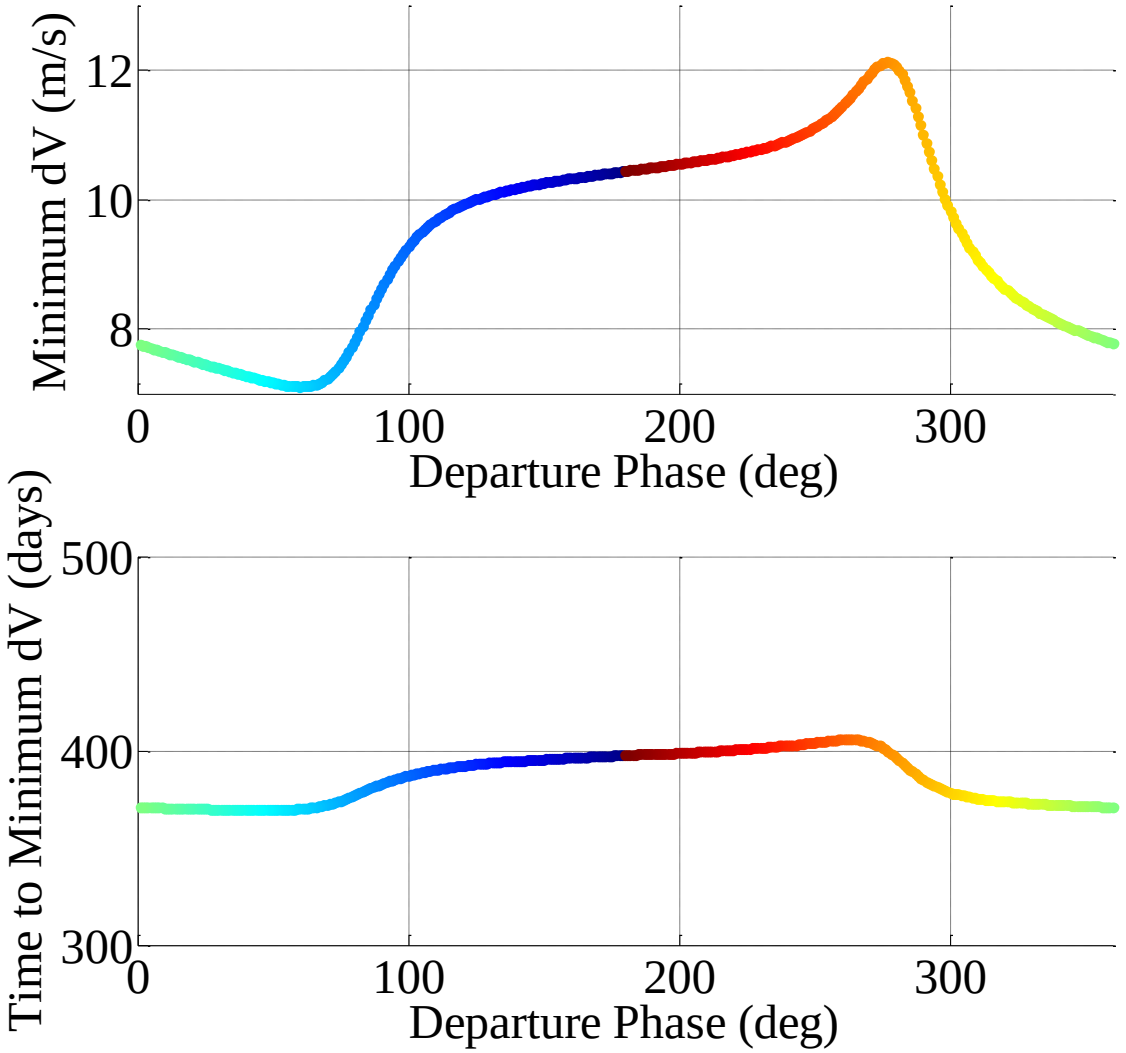


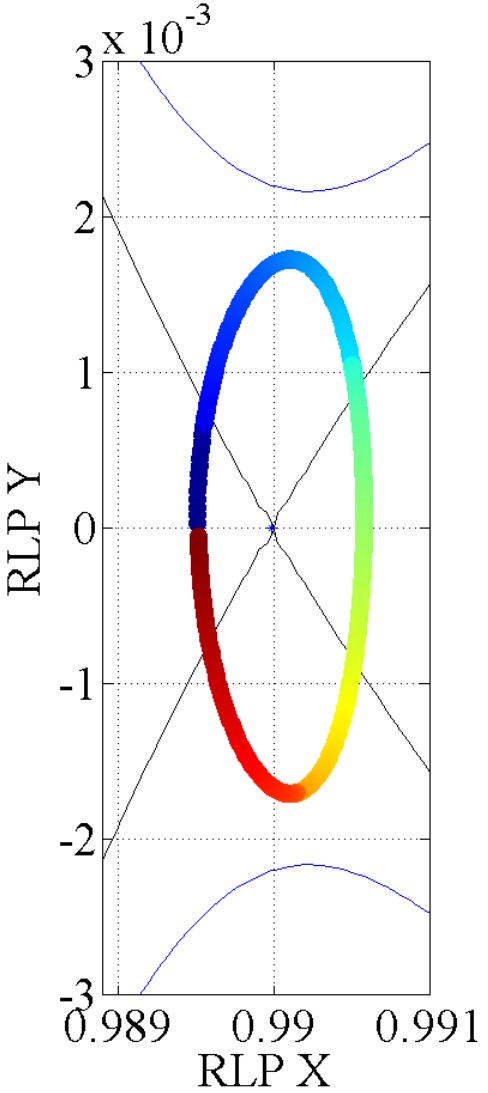


Minimum ΔV Solution

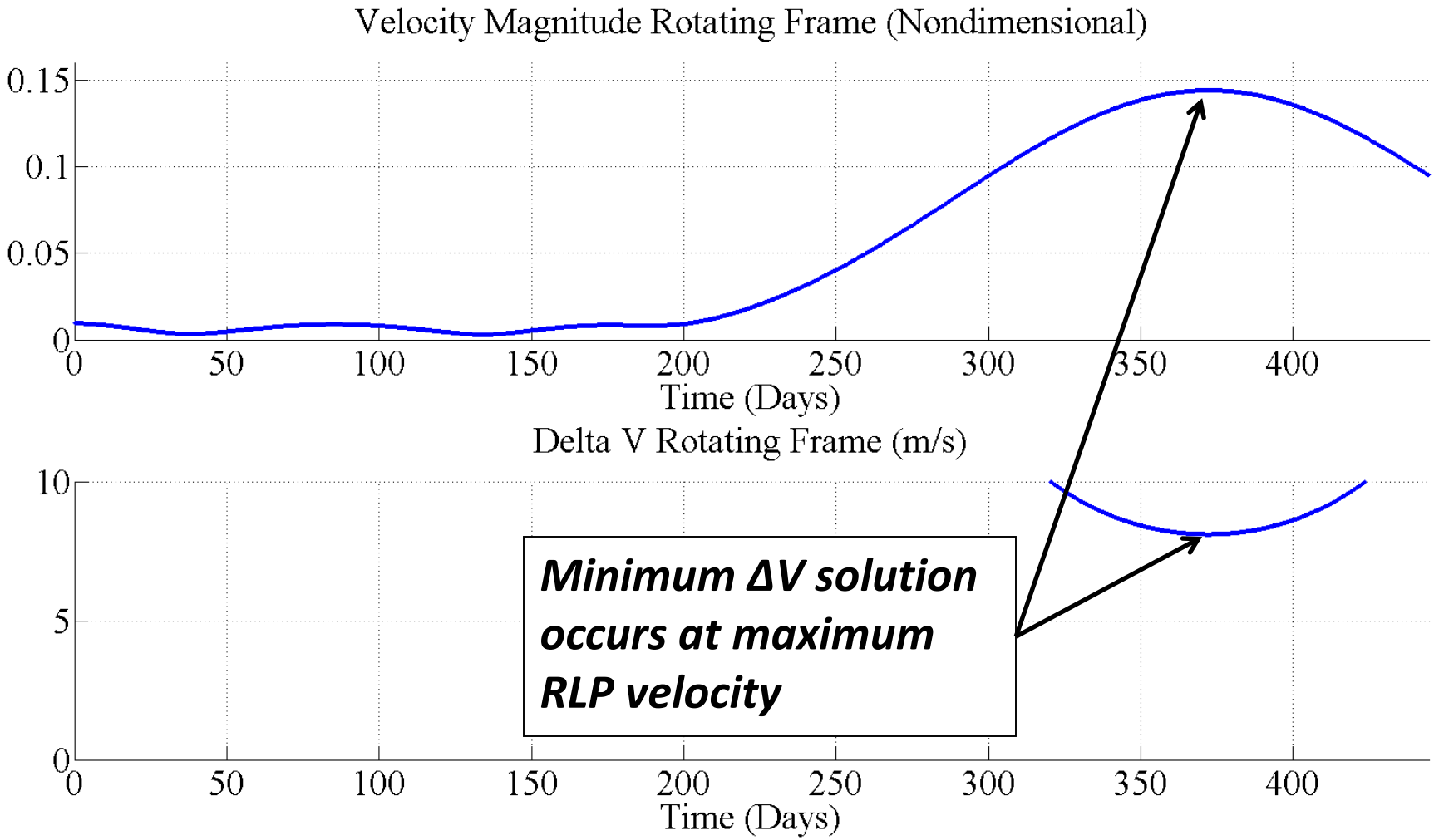


SOHO – Required ΔV

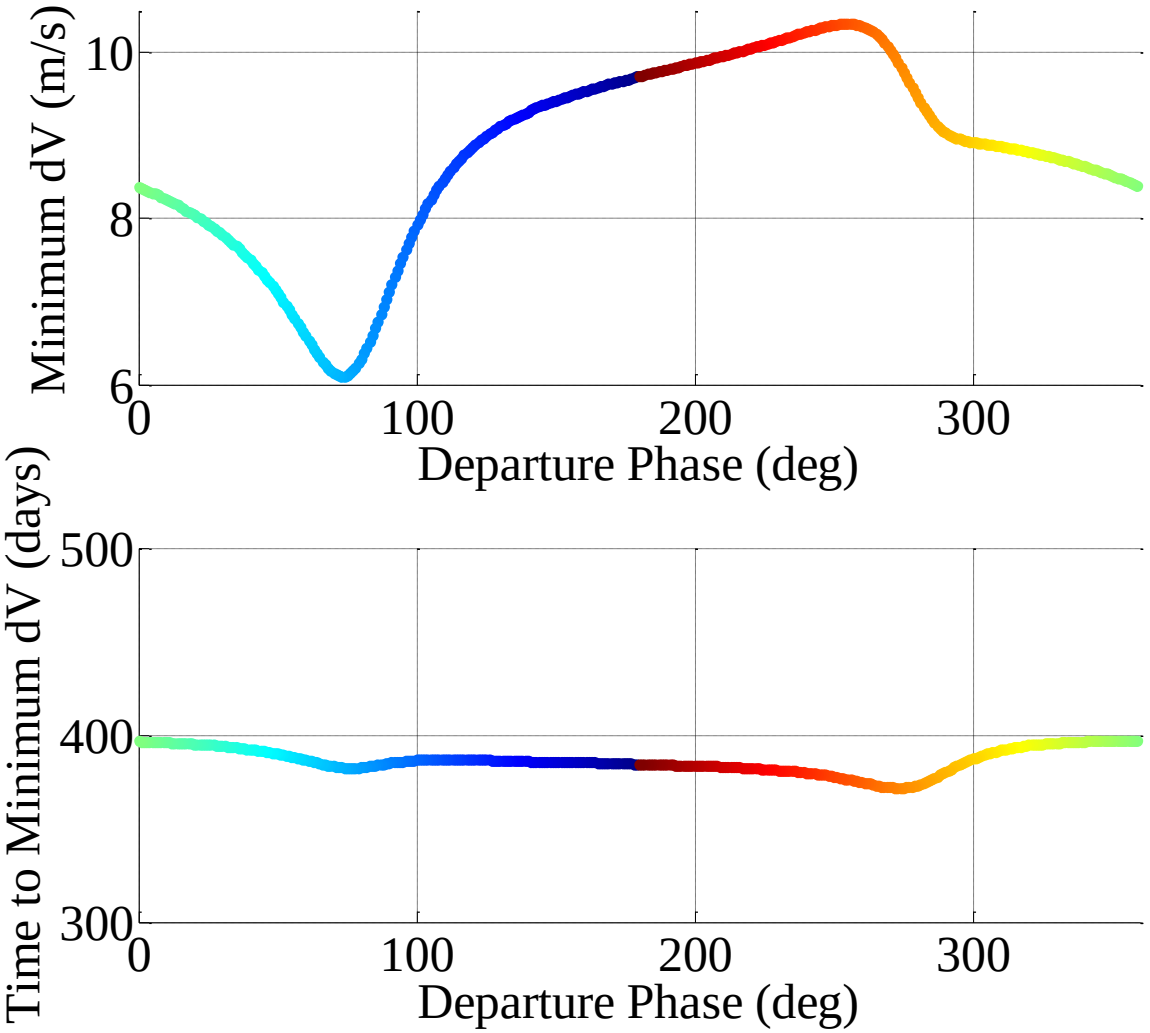


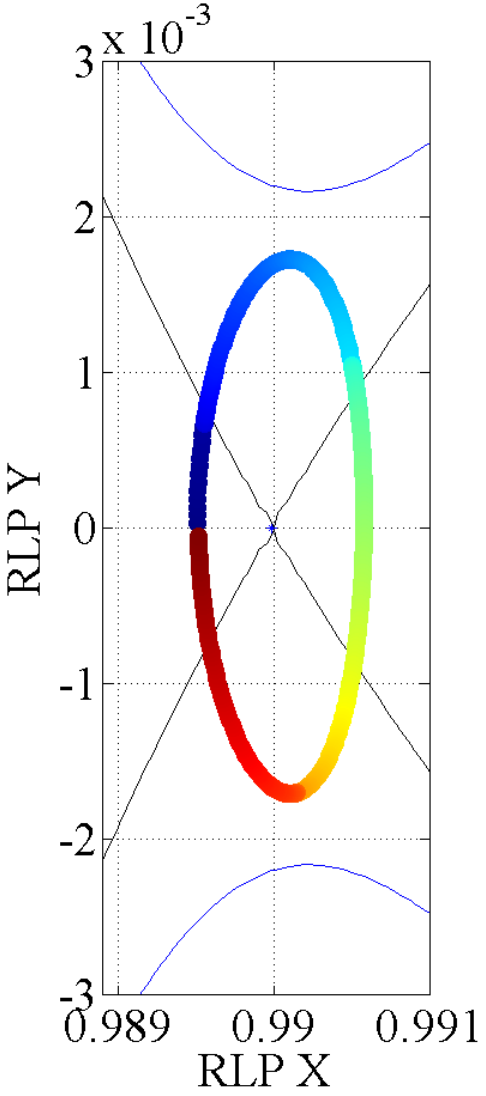


SOHO – RLP Velocity

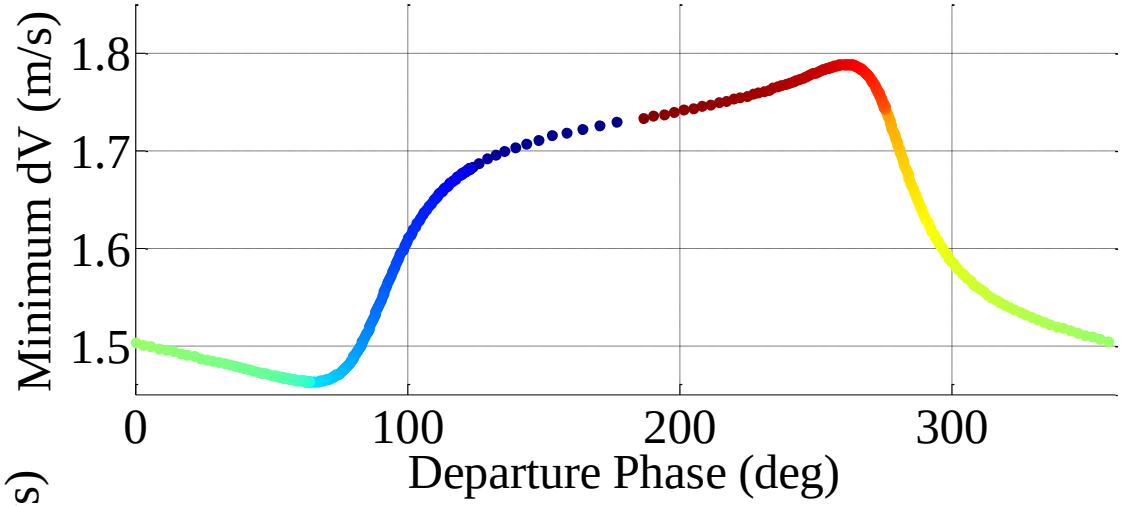


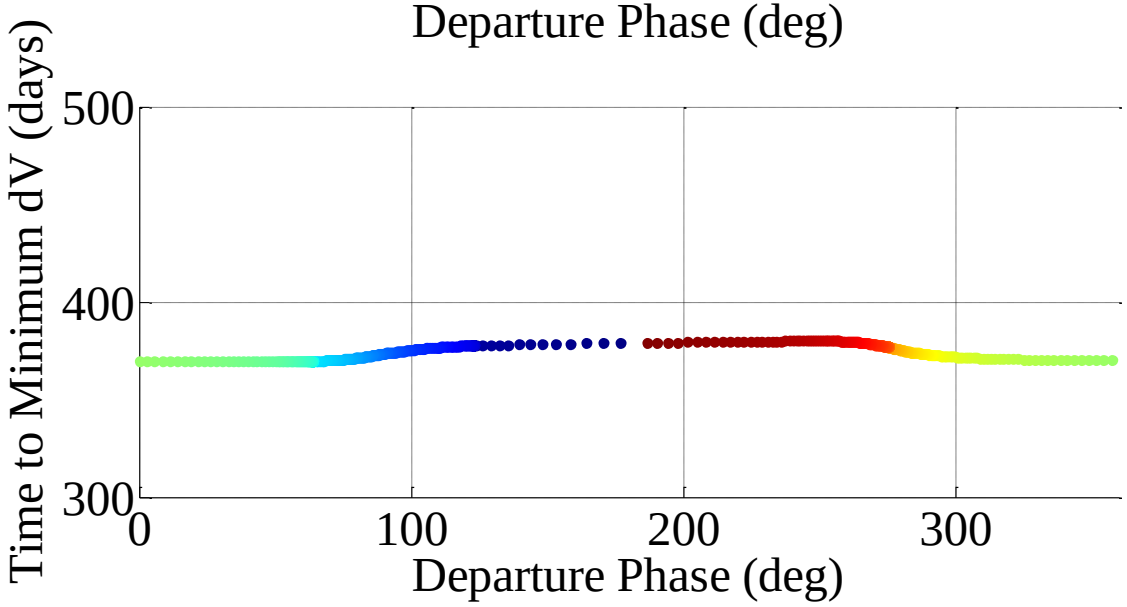
WIND – Required ΔV

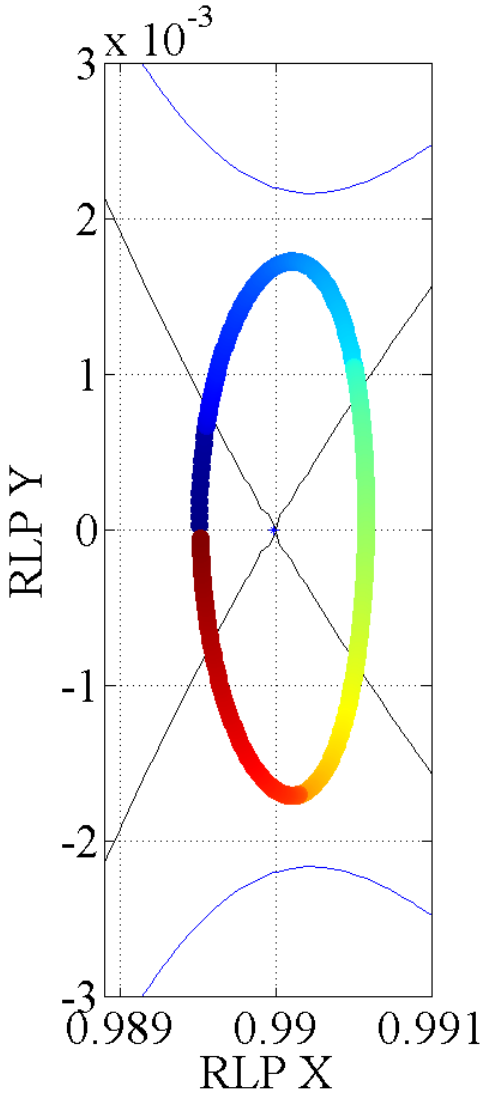




ACE – Required ΔV







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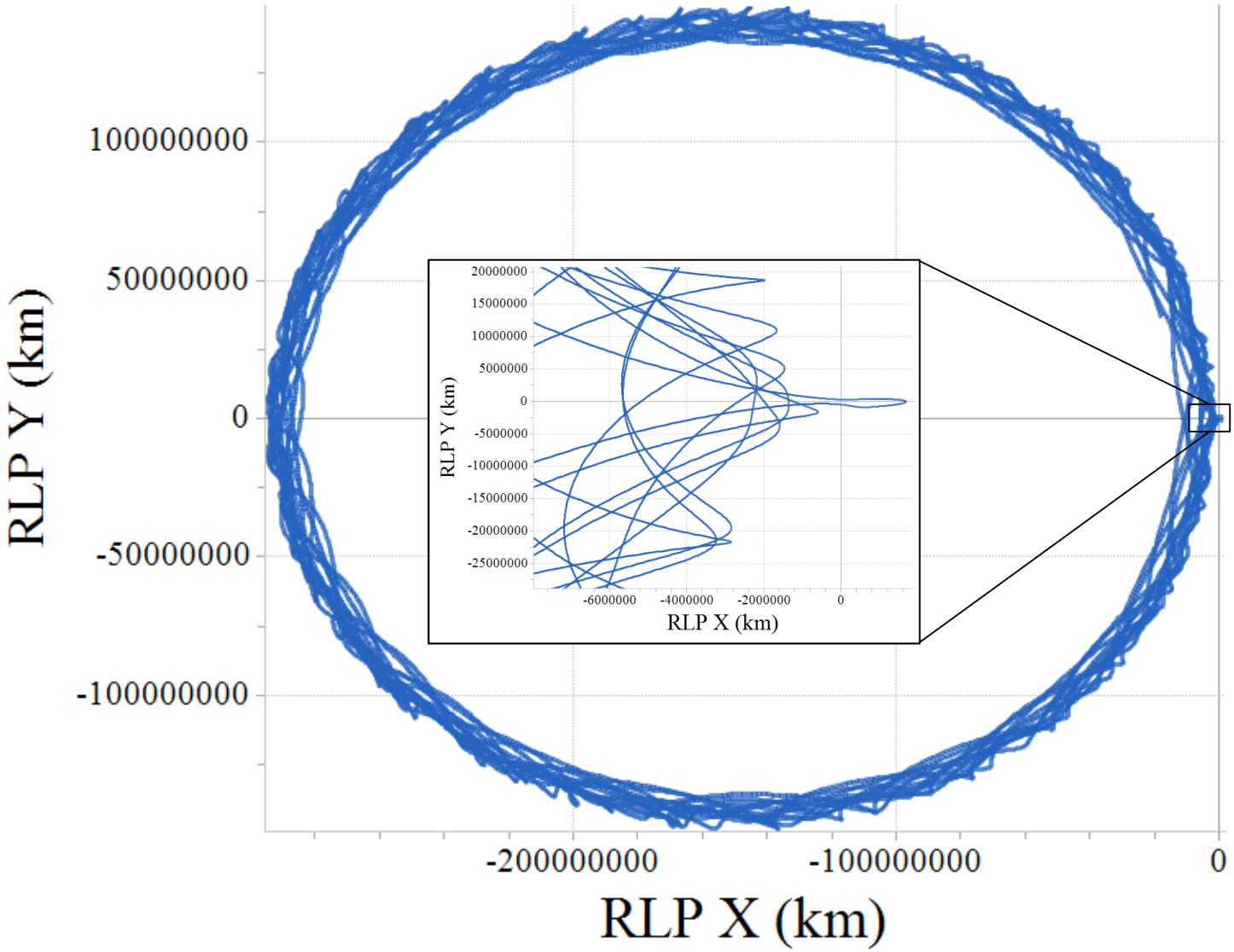
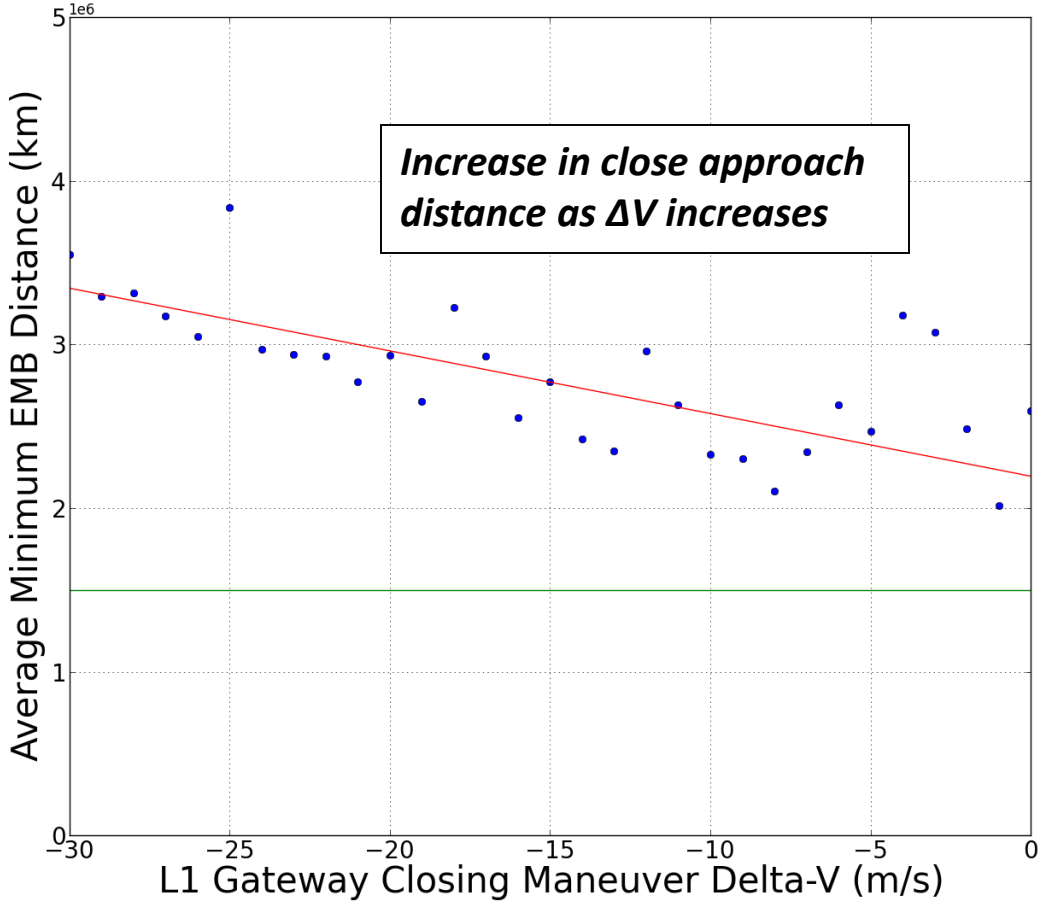
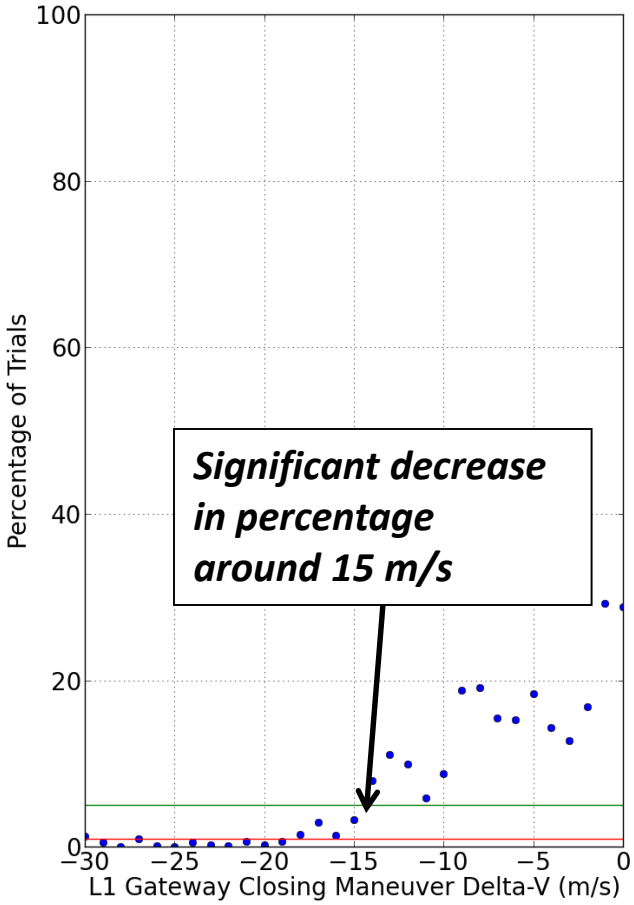
Full Ephemeris Model

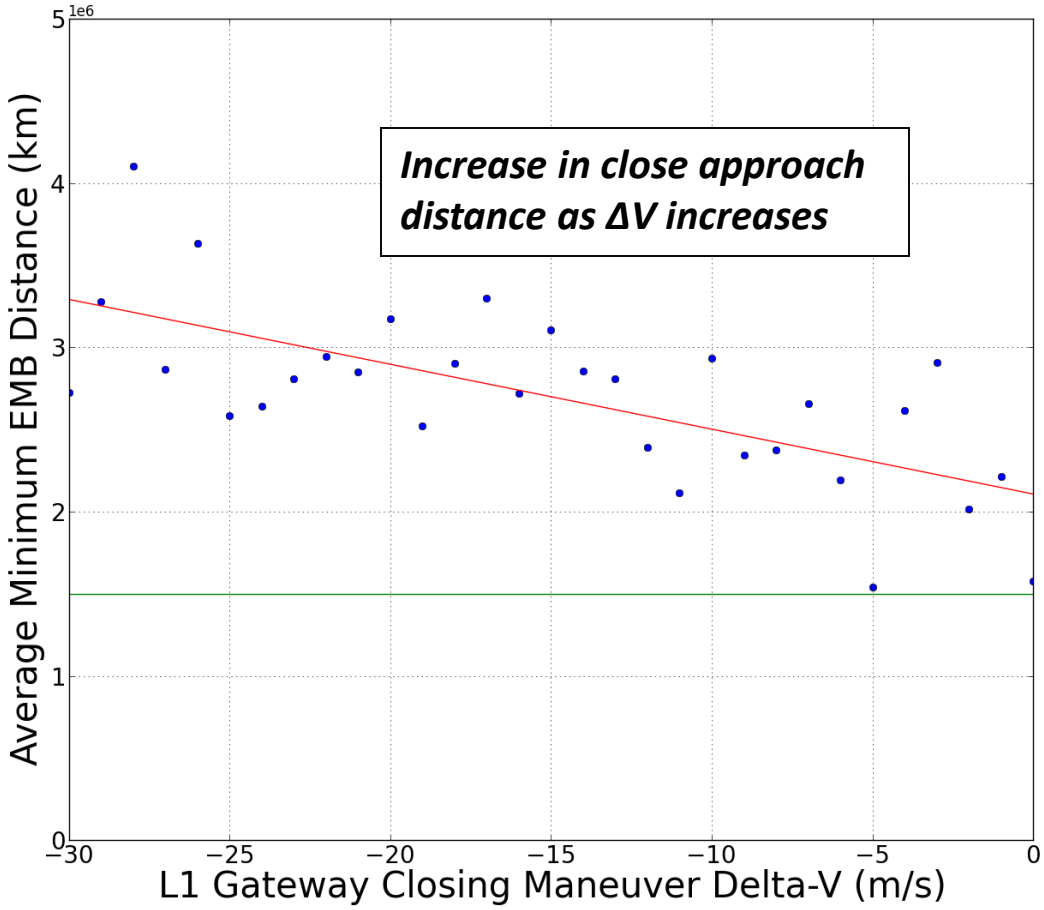


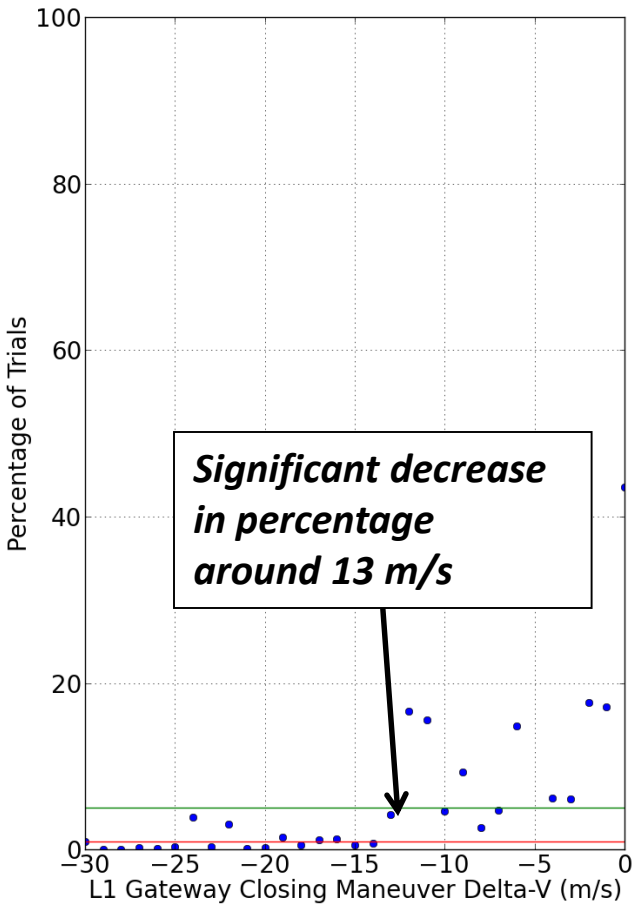
Monte Carlo Results - SOHO



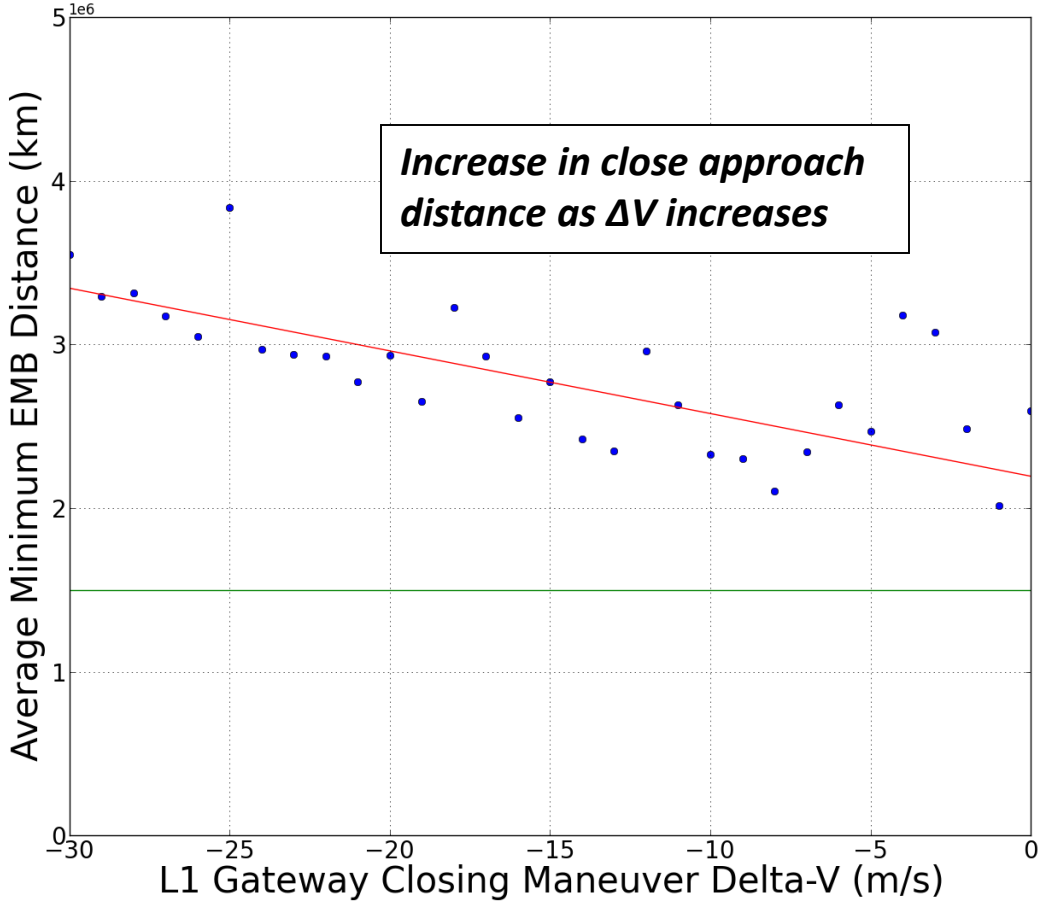


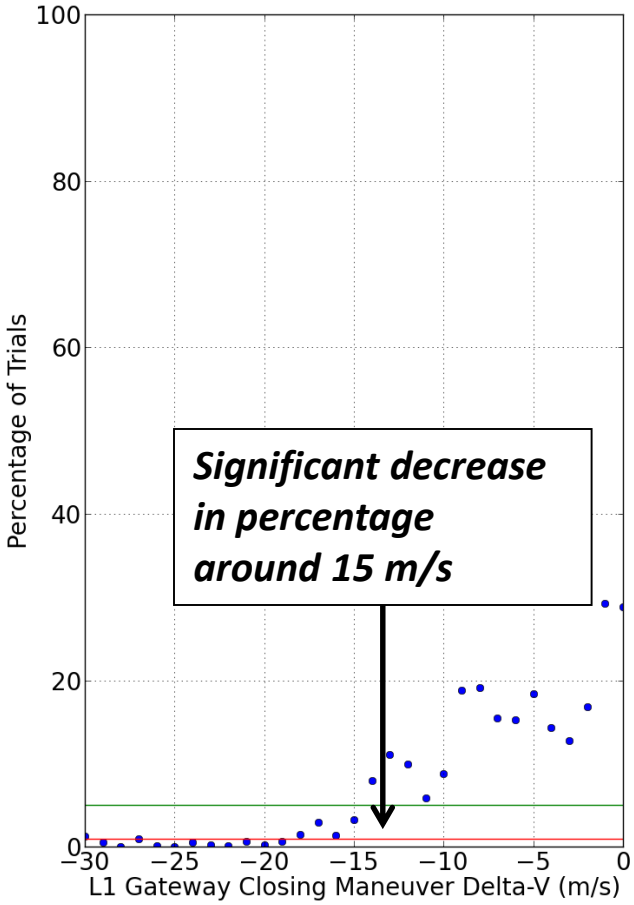
Monte Carlo Results - WIND



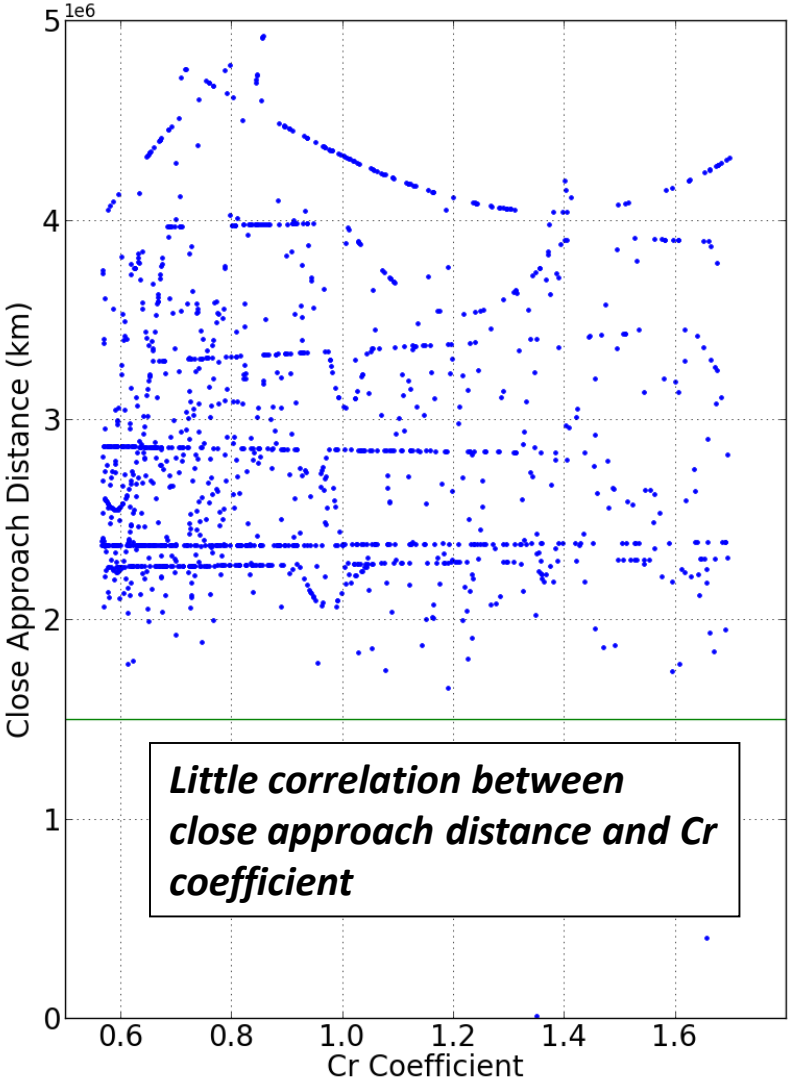


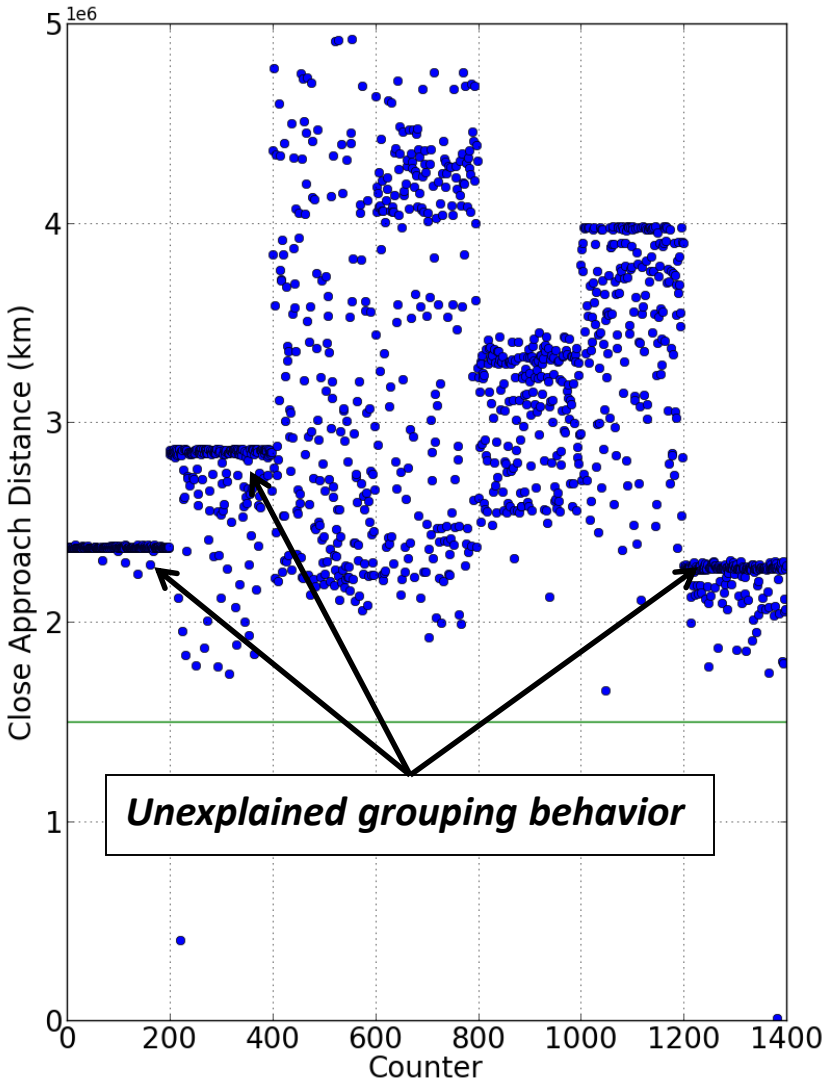
Monte Carlo Results - ACE





Monte Carlo Results – SRP Effects





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Operational Challenges

- ***SOHO***
  - Long maneuver duration due to 5% duty cycle limitation.
  - Duration could exceed a single view period with the DSN.
  - Attitude would need to be changed from Sun pointing to Earth pointing.
- ***WIND***
  - History of performing large maneuvers, would offer the fewest operational challenges.
- ***ACE***
  - Would require updated attitude control strategy to maintain Earth pointing cruise portion.
  - Largest consumer of fuel during operations.
  - Lowest amount of fuel remaining.

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Conclusion

- ***Based on analysis performed in the Circular Restricted Three Body Problem, reasonable ΔV values are achievable for closing the L1 gateway.***
  - SOHO: 6-12 m/s
  - WIND: 6-10 m/s
  - ACE: 1-2 m/s
- ***Monte Carlo analysis shows a dramatic drop in percentage of simulations returning to the Earth/Moon system at ΔV values in line with the CR3BP model.***
  - SOHO: 15 m/s
  - WIND: 13 m/s
  - ACE: 5 m/s
- ***Little correlation between the SRP force and the close approach distance.***
  - Further investigation is warranted
- ***Discussion with the each mission needs to occur to adapt strategy to real world limitations.***